EFFICIENCY TEST
OF A
HYDRO - ELECTRIC PLANT

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ARMOUR INSTITUTE OF TECHNOLOGY

1910

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AN EFFECIENCY TEST
OF A
HYDRO-ELECTRIC PLANT

A THESIS

PRESENTED BY

I. N. BAUGHMAN
A. H. CROCKER
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TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

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HAVING COMPLETED THE PRESCRIBED COURSE OF STUDY IN

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1910

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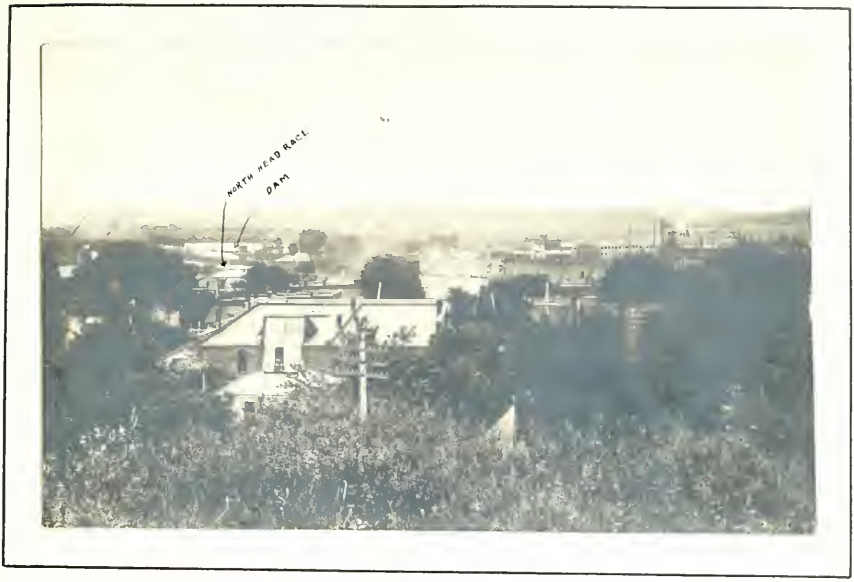
OBJECT.

The object of this test was to determine first, by direct means the efficiency of a hydroelectric plant from headrace to switch-board, and second by direct means to determine the efficiency of the wheels and their harness from headrace to generator shafts.

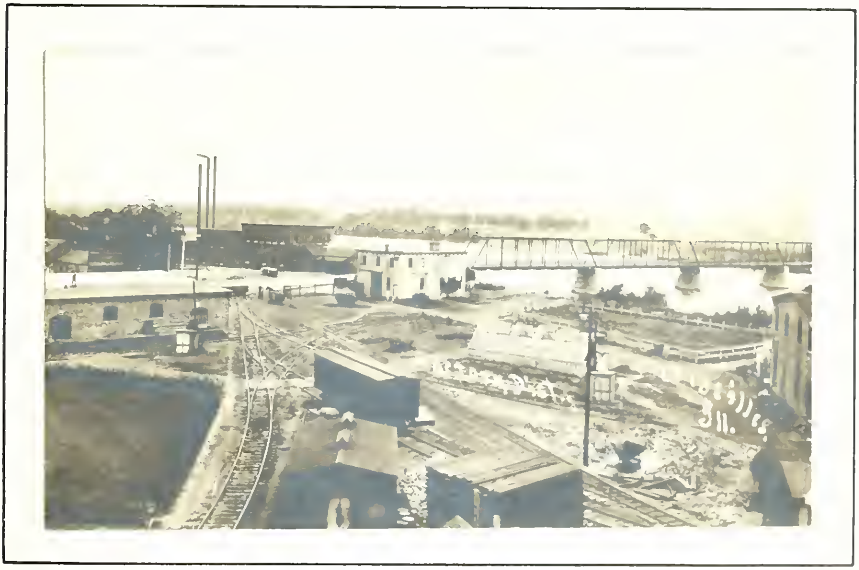
Description of Plant.

The hydroelectric plant, on which the test was made, is situated on the Illinois River at Marseilles, Illinois, and is owned by the Marseilles Land and Water Bower Company. A concrete dam diverts water from the Illinois River through two headraces supplying water for power to a number of manufacturing plants; the plant tested is near the end of the north or longer headrace. The water from the plant's wheels discharges directly into the river.

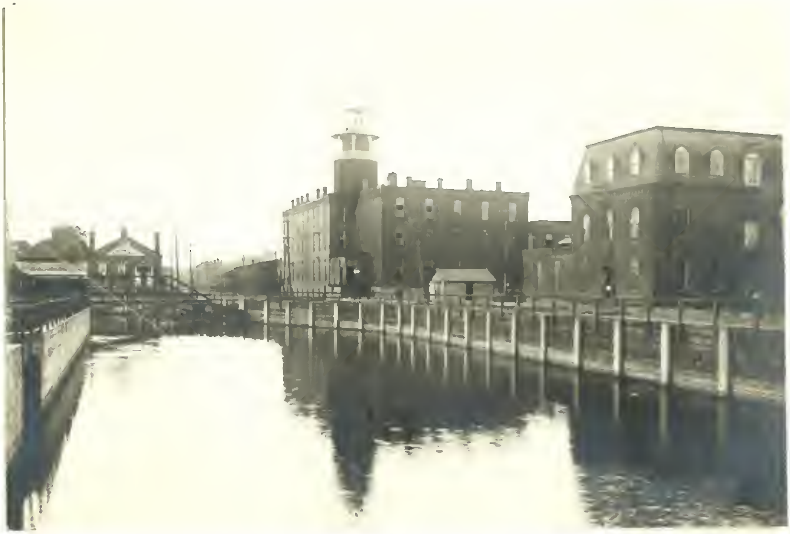
The wheel installation consists of 6 - 62 inch vertical Sampson wheels of the wicket gate type. Normal speed 70 R.P.M. on a 12 ft. head. These wheels operate on a 12 foot head and connect three level gears, gear ratio 3 to 1, to two line shafts, three on a shaft.



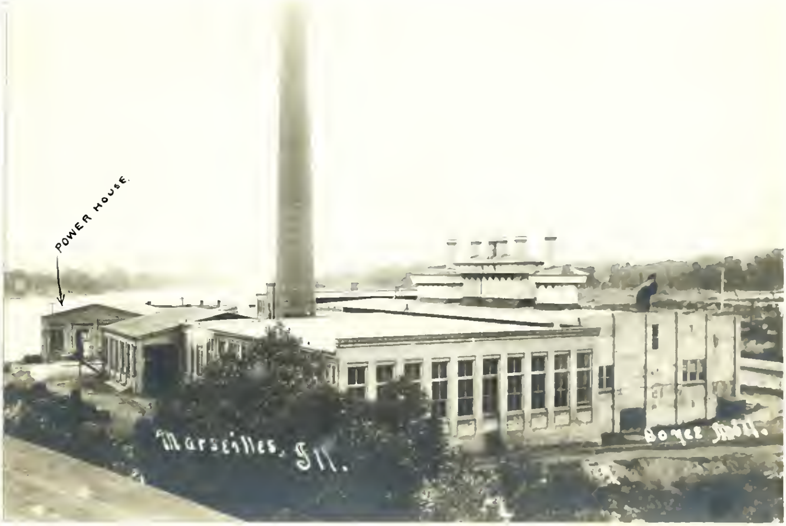
GENERAL VIEW of FACTORY DISTRICT



A CLOSER VIEW of the DAM.



A SECTION OF THE NORTH HEAD RACE.

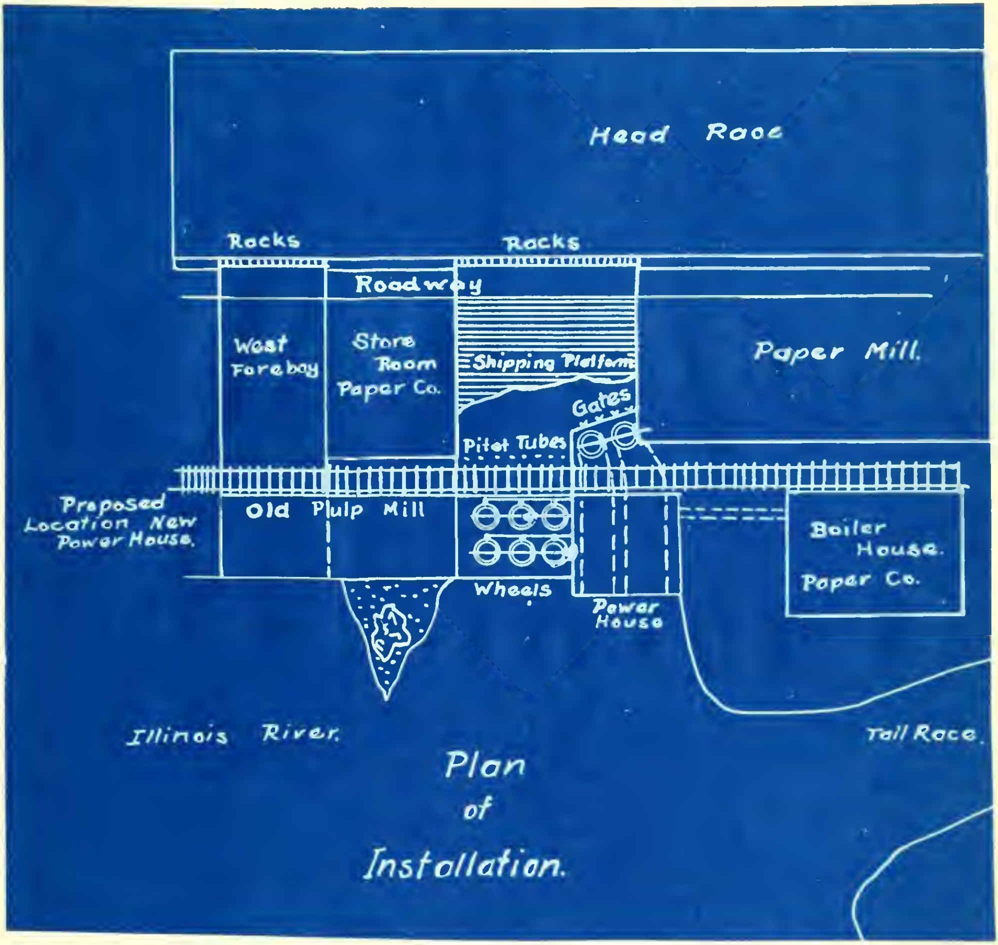


POWER-HOUSE, NORTH-HEAD RACE AND RIVER.

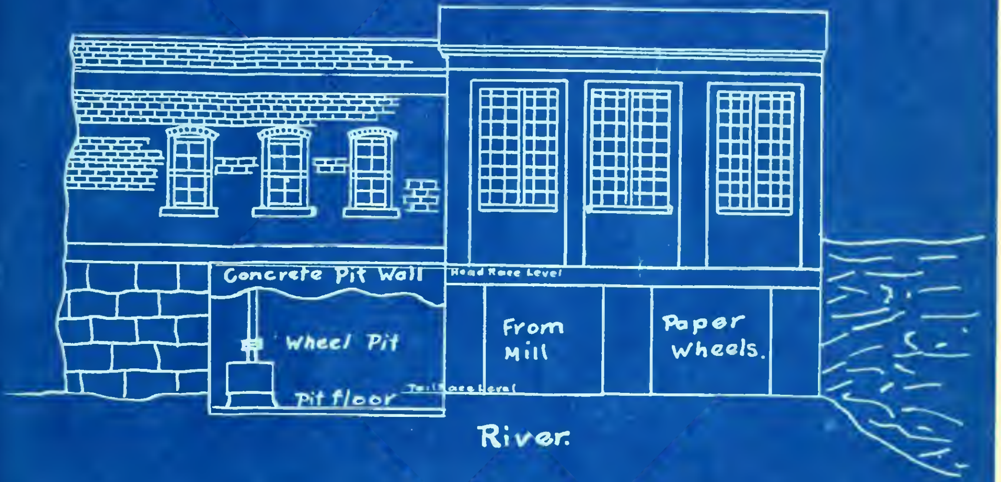
We will designate the two shafts as the north and south line shafts. Control of the wheels is maintained by two Woddward governors on for each.

On the north line shaft there are two machines, direct connected through flexible complings, an American Ball shunt wound D.C. generator of 240 K.W., capacity at 400 amps. and a Stanley (S K E System) 3 phase, 60 cycle, 2,000 volt delta connected, induction type alternator of 200 K.W. capaicty. The normal speed of two machines is 200 R.P.M. An 18x36x24 American Ball superimposed compound engine is installed in the northeast corner of the power house; it is supplied with steam from boilers in the paper mill boiler house and may be connected with the north line shaft when necessary by a jaw coupling. The engine may be rund condensing or non condensing, the condenser being located in the boiler house.

Near the west wall of the generator room, there is a large 75" pulley on the north line shaft. Two belts, one outside the other, operate two machines in the S.W. corner of the room, a 100 K.W., 125 volt, Westinghouse D.C. generator and a single phase



Plan of Installation.



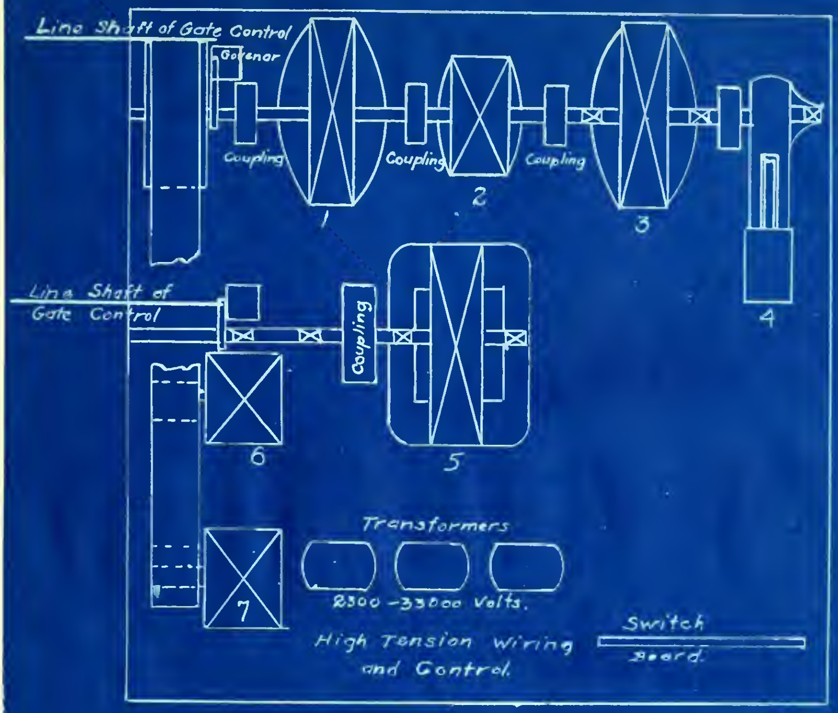
Elevation of Power House and East End of Old Pulp Mill Showing Placing of Wheels.

60 cycle General Electric alternator of 120 K.W. capacity at 1150 volts.

On the south line shaft, there is one machine, which operates direct connected through a flexible coupling. This machine is a 3-phase, 60 cycle General Electric water wheel type alternator, delta connected, of 450 K.W. capacity at 2300 volts.

Each of the above mentioned machines is connected through conduits to the switch board located in the southeast corner of the room with the exception of the 450 K.W. alternator which is operated by remote control. There are 6 panels in the switch board, one panel for each machine, besides a feeder panel, for the 450 K.W. generator, which energies a 3-phase, y connected, 33000 volt transmission line thru 3 - 300 K.W. (2300 - 3300 volt) transformers.

The lighting arrestors,switches, instrument transformers etc. for the high tension system are placed directly back of the transformers, partly on the wall and partly on a pipe frame work.

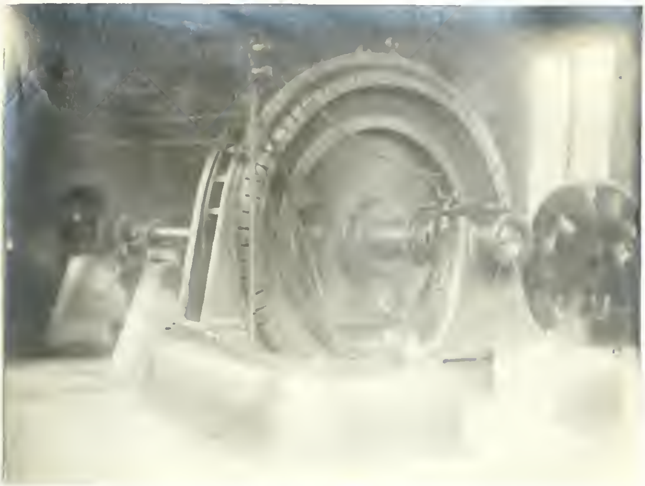


1+3	American Ball D.C. Generators	600 v. 400 amp. (#3 removed.)
2.	Stanley (S.K.C.) System A.C.	200 K.W. 2400 v.
4.	American Ball Duplex-Compound Engine.	
5.	General Electric Alt. (#176428)	2300 v. 115 amp.
6	G. E. A.C. Generator.	1040/1150 v 104 amp.
7.	Westinghouse D.C. Gen.	100 K.W. 125 v (Excites #5, #2, #6)

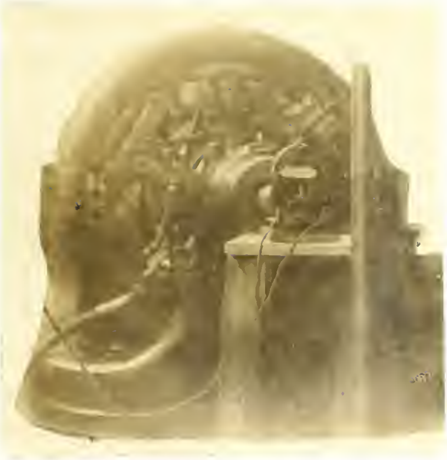
PLAN of POWER HOUSE.

PARTIAL VIEW OF GENERATOR ROOM

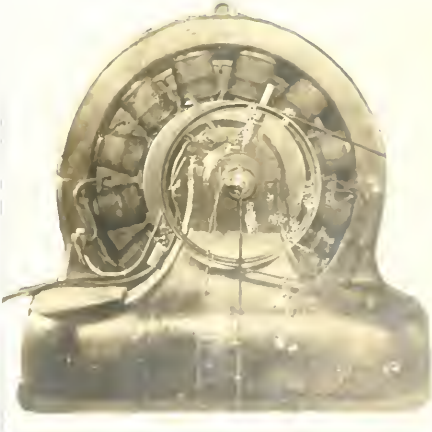
NORTH LINE SHAFT. AMERICAN BALL and STANLEY.



"G.E. AC 2300v" and SOUTH LINE SHAFT



" WESTINGHOUSE DC " (EXCITER)



"G.E. 1150 v. AC"

The building in which the generators are set is a modern, reinforceed concrete building. The wheels are located in a brick building directly to the west of the generator room. They were used formerly to operate the grinders for a pulp mill. The raceway forebay and wheel pit are of construction.

Division of Output.

The Westinghouse generator is used to excite the alternators. The 120 K.W. General Electric single phase alternator carries an incandescent lighting load in the city of Marseilles. An arc load of about 50 - 60 ampere lamps is carried by the Stanley alternator an one phase. The American Ball generator furnishes power for a motor load in the paper mill and the city pumping station. The 450 K.W. G. E. alternator supplies a high tension line as stated previously.

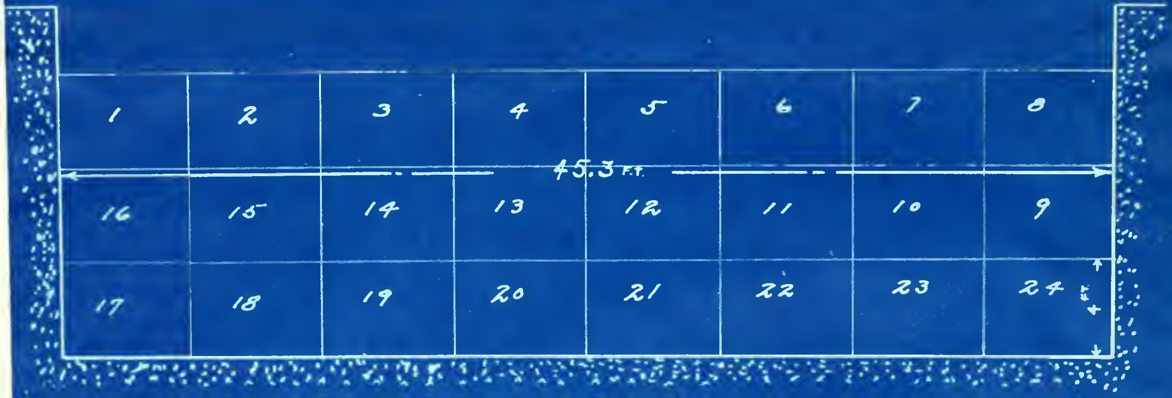
Plans for the Test.

At the outset, it was thought that the wheels might be tested directly but after consideration, it was decided that sufficient time could not be taken from the power schedule to even allow preper-

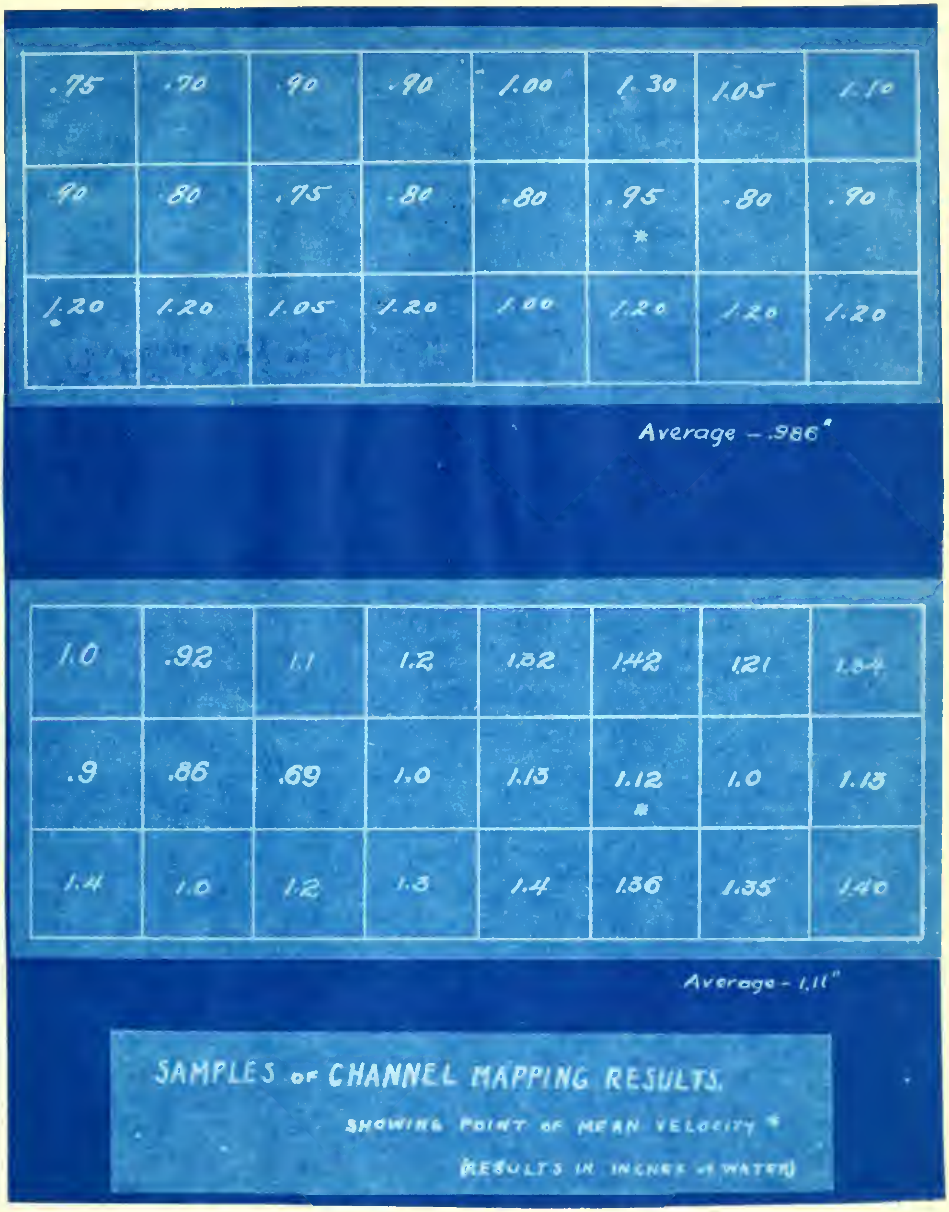
ations for such a test. The only means left, therefore for the test was to determine the output electrically. Data of performance curves for the different machines was obtained from the various manufactures and from these the power from the line shafts could be calculated.

In the measurement of the available water power input, it was decided to"map" the intake section far enough below the paper company wheels to avoid error due to eddys,and having obtained the velocities for equal parts of the sectional area, a point of mean velocity was to be determined. The water velocity measuring apparatus was to be set at this point during the test.

The mapping of the section was done as quickly as possible and at times when the load was practically constant. The point of mean velocity was determined for each test and the supposition that it remained at one point was borne out by the results obtained from a large number of mappings.



Cross Section of Channel.
Showing sections in center of which Pitot Tube was placed.



.75	.70	90	.90	1.00	1.30	1.05	1.10
90	.80	.75	.80	.80	.95 *	.80	.90
1.20	1.20	1.05	1.20	1.00	1.20	1.20	1.20

Average – .986"

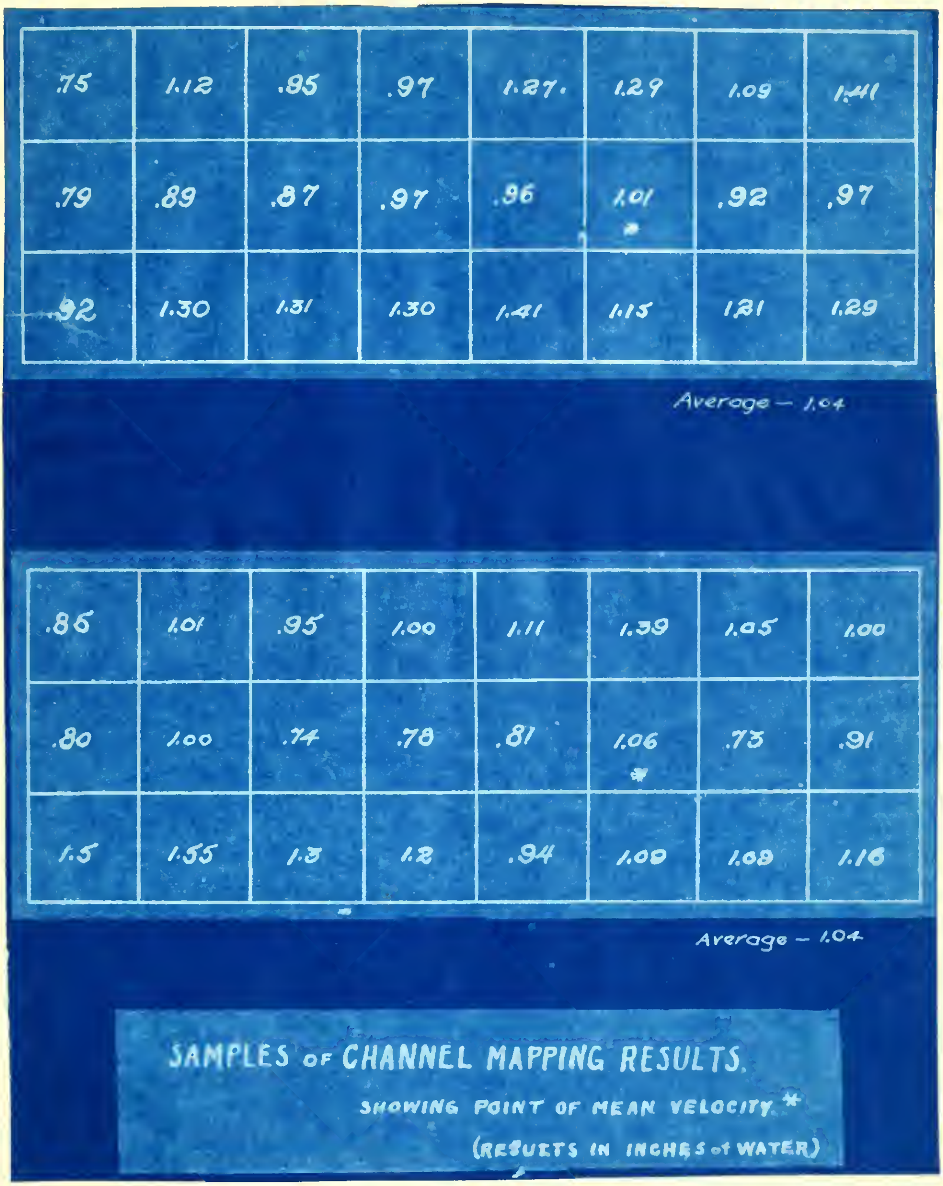
1.0	.92	1.1	1.2	1.32	1.42	1.21	1.34
.9	.86	.69	1.0	1.13	1.12 *	1.0	1.13
1.4	1.0	1.2	1.3	1.4	1.36	1.35	1.40

Average – 1.11"

SAMPLES OF CHANNEL MAPPING RESULTS.

SHOWING POINT OF MEAN VELOCITY *

(RESULTS IN INCHES OF WATER)



.75	1.12	.85	.97	1.27	1.29	1.09	1.41
.79	.89	.87	.97	.96	1.01 *	.92	.97
.92	1.30	1.31	1.30	1.41	1.15	1.21	1.29

Average — 1.04

.86	1.01	.95	1.00	1.11	1.39	1.05	1.00
.80	1.00	.74	.78	.81	1.06 *	.73	.91
1.5	1.55	1.3	1.2	.94	1.00	1.08	1.16

Average — 1.04

SAMPLES OF CHANNEL MAPPING RESULTS.

SHOWING POINT OF MEAN VELOCITY *

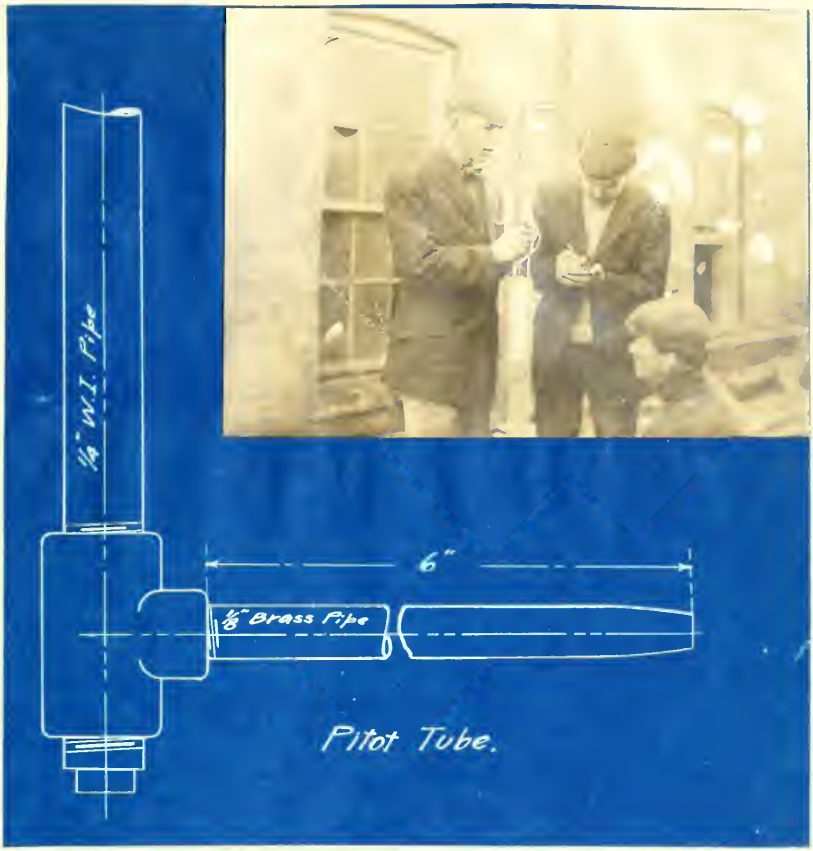
(RESULTS IN INCHES OF WATER)

Apparatus,

For Measurement of Water Velocity.

A current meter and a Pitot tube were both tested out before it was decided which would be used. The current meter was found to be in very poor running order and it was impossible to get the electrical recording attachment to operate. The necessity for large holes bing made in the race-way covering to lower the meter through would endanger switchmen handling cars in the paper mill yard, so it was finally decided to dispense with the current meter.

The Pitot tube (drawing of the velocity tube on the following page) was tried and found to be very satisfactor. A velocity tube and a pressure tube were used together, a graduated U tube being connected between the upper ends of the two. The pressure tube was necessary to balance the static pressure caused by lowering the velocity tube in the stream. The opening of the pressure tube was made about three times as long as wide in order to avoid aspiration. The opening was placed on a level with the center of the velocity tube with the long axis parallel to the velocity tube.



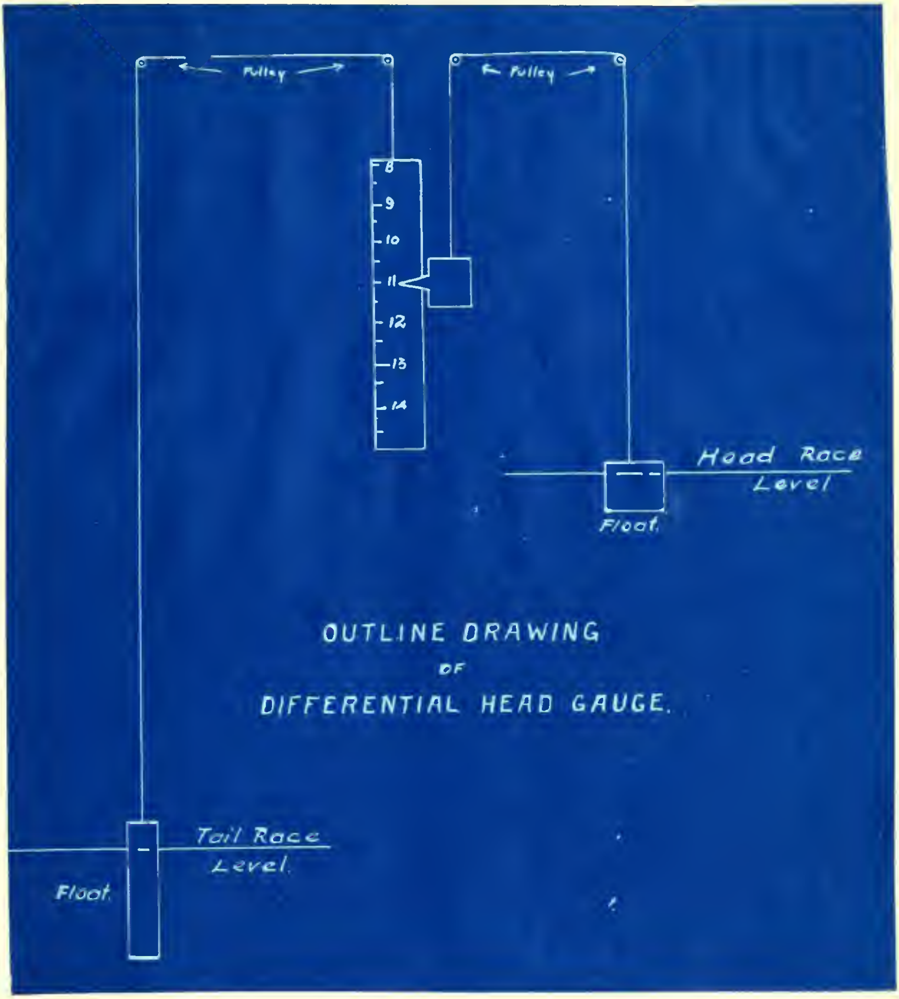
Pitot Tube.

Both the tubes and the verticals were made of small iron and brass pipe and the necessary pipe fittings, small brass tubing being soldered to the upper outlets so that connections could be made with the U-tube. All joints and the rubber tubing connections to the **U** tube were very carefully inspected for leaks.

As regards the utility of the Pitot tube, a great deal has been said and written for and against its use. A paper given by W. B. Gregory and published in the Trans. A.S.M.E., Dec. 1903, gives data which shows very fully that the constant in the formula $V = C 2gh$ is practically unity. Tests have been made using the Pitot tube to measure velocity of flow of various fluids and these all carry out this fact. It was assumed that the constant for the tube used was unity as it duplicates several mentioned in Mr. Gregory's article.

For Measuring Head.

A "differential" head gauge operated by means of floats was placed on the west wall of the generator room. (An outline drawing of the gauge is given on a succeeding page.) The pulleys used were carefully selected and kept well lubricated to reduce friction.



OUTLINE DRAWING
OF
DIFFERENTIAL HEAD GAUGE.

Flexible lines of sufficient strength connected the floats and board and a number of checkings were made on the gauge to determine whether the chords had stretched or shrunk. The sensibility of the apparatus was tested a number of times and the results showed its operation to be very highly satisfactory. The zero of the gauge was made the zero of the scale by raising the tail race float to the headrace level, (A bucket connected to the wheel pit by a siphon) and adjusting the lengths of the chords. The scale of the gauge was graduated in feet and tenths of feet.

For Measuring Intake Cross Section.

As the head gauge operated differentially it was necessary to measure the depth of water in head race by other means.

The wheel pit level being above the generator room floor by about a foot, a siphon from the Pitot tube section of the forebay into the generator room was connected to a graduated tube on the floor. The depth at the section was carefully measured and the tube reading was taken at the same time thereby fixing the relation between the two.

The scale was then marked to read directly the depth of the section. Care was exercised in constructing the siphon to avoid leaks and it was tested for the same. The scale was graduated in feet and tenths of feet.

For Measuring Output.

Calibrated electrical instruments were used in parallel and series with the station instruments except, in the case of the ammeter on the American Ball generator panel and the potential transformers on the 450 K.W. alternator leads. The former was calibrated later and the latter's accuracy was vouched for by the manufacturers.

The Westinghouse output was measured by a calibrated voltmeter and a standard .0001 ohm shunt and a calibrated milli-volt meter.

The Ball generator output was determined with a calibrated voltmeter and the station ammeter, the ammeter being checked later with standard shunt and milli-volt meter as stated above.

The G. E. 120 K.W. alternator, (designated in the Running Log as "G.E. 1150 V.") output was measured

by a Weston indicating wattmeter, calibrated previously.

The Stanley alternator's output was also measured by a calibrated Weston indicating wattmeter.

With the 450 K.W. G.E. alternator a calibrated Westinghouse polyphase wattmeter was used in conjunction with Standard Westinghouse current portable transformers. The potential transformers installed in the station were also used with it as stated previously. Alternating current ammeters and an A. C. voltmeter were used in parallel with it to determine the power factor approximately. These power factor values were used with the efficiency curves given for the generator.

Measurement of R.P.M. of Shafts and Generators.

Four commutators and a frequency meter supplied by direct current were used to measure the rotative speeds of the line shafts and two belt driven generators.

Method of Procedure.

The electrical measureing apparatus used was obtained from the Electrical Department and carefully calibrated on the calibrating bench against standards two days before the test.

The instruments were very carefully handled in transit to Marseilles, being taken as hand luggage.

The mapping of the channel and the erection and testing of the "water" indicating devices required several days. Previously the electrical measuring apparatus had been connected up and its action was watched closely during this time. When not in use all instruments were disconnected or shunted.

Affor having finished the mapping of the channel and the testing of the various water measuring devices a run of ten hours was started. The run was taken during the night owing to the fact that the arc circuit was only on then and the Stanley alternator could not be disconnected without stopping the north line shaft.

Readings of all electrical measuring apparatus, R.P.M. of shafts and generators, depth of water at pitot tube section, velocity of water in channel in inches of water and the head reading were taken every twenty minutes during the run.

Method of Calculation.

Water End.

The U tube being filled with water gave the velocity head reading in inches of water. The scale was calibrated in inches and tenths. From this reading the mean velocity of the section was calculated by the formula $V = \quad 2gh$ where h = reading of U tube in inches of water divided by 12.

Having obtained the velocity of flow v, the cubic feet of water passing the section per second was obtained by multiplying v by the depth of the section and 45.3, the average width of the section (obtained from drawings and checked by measurements). The weight of water per second was obtained by multiplying by the weight per cubic foot. From the weight of water and the corresponding head the foot-pounds per second were calibrated. This value multiplied by the fraction $\frac{.746}{550}$ gave the "Available power in the Headrace" in kilowatts.

The product of the voltmeter and ammeter readings (corrected) of the direct current machines divided by 1000 gives the out put in K.W. The alternator outputs were given directly by the wattmeter readings.

The sum of all outputs, excluding the Westinghouse output, gave the "Total Available Output" at the switch board.

The Westinghouse output is used in excitation and therefore is not available at the switch board except as a part of the A.C. output.

Having the "Total Available Output", the efficiency from headrace to switch board is obtained by dividing this figure by the "Available Power in the Headrace", (Head race being used to denote the intake below the paper company's wheels).

Total Input (To Electrical Machinery).

The input to each of the machines, with the exception of the Stanley, was obtained by interpolation from the "Input Output Curves" ~~following~~ the curves were drawn from the following data submitted by the companies and tabulated on a succeeding page.

In the case of the Stanley, the output was divided by .70% to obtain the input. This figure (.70%) was given by the designer who was connected with the manufacturers at the time the machine was

built, and has been taken as correct for the conditions of operation.

Having obtained the five inputs, the Westinghouse output was subtracted, from the sum, and the result giving the "Total Input".

The Westinghouse output was subtracted owing to the fact that the sum of power used in excitation and the power from the line shafts represents the input to the alternators. Since the Westinghouse input was added to the "Total Input" subtraction of its output is thereforo necessary.

Having obtained the "Total Input" to the machines the "Efficiency of wheels and Harness" was obtained by dividing the "Total Input" by the "Available Power in the Head Race".

Sample Calculations.

(7:00 P.M. Readings)

Water End.

"Velocity Head", h, (inches of water = 1.1 in.

"Velocity, (ft. per second)

$v = \sqrt{2gh} \quad \sqrt{64.4 \quad \frac{1.1}{12}}$ = 2.42 ft. per Sec

"Depth in Head Race", $\underline{d}$ =11.52 ft.

"Area of Section of Flow" sq.ft.)

$A = 45.3 \times d = 45.3 \times 11.5$ (2) =522.0 sq.ft.

"Cubic feet per second",

$Q = Av = 522. \times 2.42$ = 1265.5 cu.ft.

"Pounds per Second"

$W = Q\gamma = 1265.5 \times 62.4$ =79000 lbs./Sec.

"Head" h, (ft) =11.51 ft.

"Foot Poundd per Second",

$E = Wh = 79000 \times 11.51$ = 909100 lbs./Sec

"Available Power in Head Race (KW),

$P = E \times .746/550 = 909100 \times \frac{.746}{550} =$ = 1232.5 K.W.

Electrical End.

Output.

American Ball Generator, (KW) $= \frac{EI}{1000} = \frac{415 \times 133}{1000} =$ 55.2 K.W.

"Westinghouse generator" (KW) 8.4 K.W.

$\frac{E\ I}{1000} = \frac{102.7 \times 82}{1000} =$ 8.4 K.W.

"G.E. 1150v. alternator (KW)

Corrected Wattmeter Reading = 63.5 K.W.

Stanley alternator K.W.

Corrected Wattmeter Reading = 22.6 (5) K.W.

G. E. 450

Electrical End.

(Output)

"American Ball D.C."

$$\frac{E\ I}{1000} = \frac{415 \times 133}{1000} = \qquad = 55.2\ K.W.$$

"Westinghouse D.C." = 8.4 (2) K.W.

"G.E. A.C. 1150 v."

Alternator Reading 63.5 K.W.

"Stanley A.C."

Wattmeter Reading 22.6 (5) K.W.

"G.E. A.C. 2300 v."

Wattmeter Reading. 122.0 K.W.

(P$^1_2$) Total Available Output -

Input.

"American Ball D.C. (Interpolated from curve) 65.3K.W.

"Westinghouse D.C." (" " " 21.0(5) K.W.

"G.E. A.C. 1150 v. " " " 72.5 K.W.

"Stanley A.C. (Output) 32.7 K.W.

"G.E. A. C. 2300 v. (Interpolated from curve(PF.6) 165.0 K.W.

Apparent total input 356.0 K.W.

Westinghouse Output 28.4 K.W.

Total Input (P^{11}) to generator & Alternarors) 388.2 KW.

Efficiency Head race to Switch board

$l_1 = \frac{P^1}{P} = \frac{273.4}{1232.5}$ (x 100%) = 22.2%

"Efficiency Wheels & Harness"

(Headrace to Electrical Machinery)

$l_2 = \frac{P^{11}}{P} = \frac{348.2}{1232.5}$ (x 100%) = 28.25%

RUNNING LOG.

Time	Ball Generator D.C.				Westinghouse. D.C.				Stanley A.C. Kw.	G.E. A.C. 1150 volts Kw.	General Electric A.C. 2300 V.					Speeds. R.P.M.				Head Ft.	Depth of Head Race Ft.	Velocity in Channel In. of Water.
	A		V		A		V				Watts	A		V		Westinghouse.	G.E. 1150v.	South L.S.	North L.S.			
	Ind.	True	Ind.	True	Ind.	True	Ind.	True				#1	#2	#1	#2							
P.M. 7:00	135	133	415	415	82	82	104	102.7	22.65	63.5	305	2.95	2.17	114	109	505	610	200	185	11,51	11,52	1.1
20	140	138	420	420	82	82	104.7	103.5	24.75	63	310	3.0	2.22	114.5	109	505	610	200	185	11,52	11,51	1.1
40	135	133	420	420	82	82	106	104.75	25.85	64	310	3.0	2.15	115.	110	505	610	200	186	11.51	11,51	1.1
8:00	130	128	440	440	82	82	109	107.6	27.15	65	350	2.87	2.1	113.8	108.8	505	610	205	185	11,52	11,51	1.0
20	140	138	435	435	81	81	107	105.6	26.15	59	305	2.8	2.18	115.2	109.8	505	610	205	185	11.58	11,52	1.1
40	138	136	438	438	82	82	108	106.7	26.45	59.8	281	2.3	2.02	115	112	505	610	205	185	11.6	11,52	.95
9:00	140	138	426	426	78	78	106	104.75	25.15	52	285	2.1	1.92	115.4	110.7	505	620	205	185	11.61	11,55	.95
20	143	141	436	436	80	80	108	106.7	26.45	49.2	280	2.0	1.83	116	111.5	505	620	205	185	11.7	11,55	.93
40	134	132	440	440	80	80	108	106.7	26.55	46.2	270	1.8	1.75	116.5	112	505	610	205	185	11.71	11.57	.92
10:00	145	143	435	435	78	78	106	104.75	26.65	38.2	247.5	2.28	1.5	115.5	112	505	610	210	185	11.73	11.57	.80
20	135	133	433	433	80	80	107.5	106.2	25.65	37.3	228	1.30	1.35	116.2	112	505	610	210	185	11.78	11.58	.79
40	133	131	435	435	80	80	106	104.75	26.05	32	220	1.30	1.30	115.6	112.3	505	610	210	185	11.8	11.57	.79
11:00	143	141	432	432	79	79	105	103.7	26.15	30	200	1.20	1.29	116	112.2	505	610	210	185	11.85	11.60	.76
20	134	132	440	440	78	78	107.5	106.2	25.45	27.3	190	1.10	1.17	115.7	112.7	505	620	210	185	11.85	11.60	.75
40	142	140	435	435	80	80	108.2	106.8	25.75	24	185	1.09	1.14	114.7	111.6	505	620	210	186	11.87	11.60	.76
12:00	128	126	435	435	80	80	107	106.6	25.65	23.5	183	1.10	1.13	115.2	112.1	505	620	210	185	11.88	11.61	.79
20	121	119	440	440	79	79	108.5	107.2	26.45	21.4	200	1.35	1.17	114.8	111.2	505	610	210	185	11.89	11.60	.96
40	170	168	425	425	79	79	106	104.75	25.55	21.6	197	1.35	1.17	114	110.3	505	620	210	185	11.89	11.60	.97
1:00	175	173	430	430	80	80	109	107.6	26.55	20	209	1.35	1.17	114.3	110.3	505	610	210	185	11.88	11.59	.97
20	160	158	425	425	77	77	107	105.6	25.35	19.5	201	1.35	1.18	114	110.3	505	610	210	185	11.90	11.60	1.0
40	155	153	445	445	76	76	107.5	106.2	23.65	20	215	1.35	1.20	114	110.8	505	610	210	185	11.90	11.59	.90
2:00	165	163	433	433	76	76	106.9	105.55	25.15	20.6	201	1.35	1.20	113.8	110.	505	620	210	185	11.91	11.59	.90
20	155	153	438	438	77	77	108.3	106.9	26.65	22.6	208	1.36	1.20	114	110.5	505	620	210	185	11.92	11.59	.90
40	160	158	435	435	77	77	107.6	106.2	26.15	20.9	203	1.33	1.18	112.7	109	505	620	210	185	11.93	11.57	.90
3:00	157	155	437	437	77	77	108.2	106.7	26.15	20.5	210	1.35	1.19	113	109.5	505	620	210	185	11.94	11.56	.90
20	165	163	432	432	77	77	107.5	106.2	26.15	21.4	210	1.33	1.20	113	109.5	505	620	210	185	11.93	11.57	.85
40	161	159	438	438	75	75	106.7	105.3	26.85	21.4	200	1.33	1.20	113	109.7	505	620	210	185	11.94	11.53	.80
4:00	165	163	435	435	76	76	105.8	104.6	25.80	21.5	210	1.33	1.20	113	109.	505	620	210	185	11.95	11.56	.80
20	164	162	438	438	76	76	106.3	105	26.15	21.6	214	1.33	1.20	113	109.4	505	620	210	185	11.95	11.58	.80
40	160	158	440	440	77	77	106.7	105.3	25.75	21	197	1.36	1.20	112.8	109	505	620	205	185	11.95	11.59	.80
5:00	162	160	432	432	76	76	106.4	105.1	22.75	22	200	1.40	1.22	112.7	1082	505	620	205	185	11.95	11.60	.80

DATA SHEET.

Time.	Velocity in ft/sec.	Head in feet.	Depth in Head Race	Area of Section of Flow, □ft	Cubic Feet per Sec.	Pounds per Second	Ft. Lbs. per Second	Available Power in Head Race K.W.
7:00	2.42	11.51	11.52	522	1265.5	79000	909100	1232.5
20	2.42	11.52	11.51	521.3	1264.	78800	908900	1232.
40	2.42	11.51	11.51	521.3	1264	78800	908000	1231.5
8:00	2.32	11.52	11.51	521.3	1280	79870	920000	1247.5
20	2.42	11.58	11.52	522.	1265.5	79000	915000	1241
40	2.26	11.6	11.53	522.	1174.5	73600	854000	1157.5
9:00	2.26	11.61	11.55	523.	1182.	73780	856000	1160.
20	2.34	11.70	11.55	523.1	1168	72900	853800.0	1156.5
40	2.22	11.71	11.57	523.3	1162.5	72500	849100	1151.
10:00	2.07	11.73	11.57	524.	1035.5	67700	794000	1076.
20	2.12	11.78	11.58	524.5	1080.	67400	794000	1077.5
40	2.12	11.80	11.57	524.	1079.	67350	795000	1063
11:00	2.02	11.85	11.60	525	1060	66150	784000	1057
20	2.01	11.85	11.60	525.4	1054.5	65800	780000	1052.4
40	2.02	11.87	11.60	525.4	1061.5	66220	776000	1052.4
12:00	1.90	11.88	11.61	525.5	1047.	65320	776000	1075
20	2.32	11.89	11.60	525.4	1192.5	74400	742800	1204
40	2.20	11.89	11.60	525.4	1197.5	74700	888000	1204
1:00	2.20	11.88	11.59	525.2	1197.4	74700	888000	1273
20	2.42	11.90	11.60	525.	1266.	79000	940000	1162
40	1.46	11.90	11.59	525.2	1154.	72000	856800	1160
2:00	2.2	11.91	11.60	525.	1153.5	71950	856000	1162
20	1.96	11.92	11.59	525.	1153.5	71950	857200	1161.5
40	1.46	11.93	11.57	524.	1151.5	71800	856500	1161.5
3:00	2.2	11.94	11.56	523.8	1150	717500	856500	1031.5
20	2.14	11.93	11.57	524.	1118.5	63900	761000	1091.5
40	1.96	11.94	11.52	522.	1081.5	67450	805200	1092.4
4:00	2.07	11.95	11.56	523.8	1085.	67700	805500	1094
.20	2.07	11.95	11.58	524.3	1087	67840	807100	1094
40	2.07	11.95	11.59	525.	1087	67840	807100	1094
5:00	2.07	11.95	11.59	525	1087	67840	807100	1094

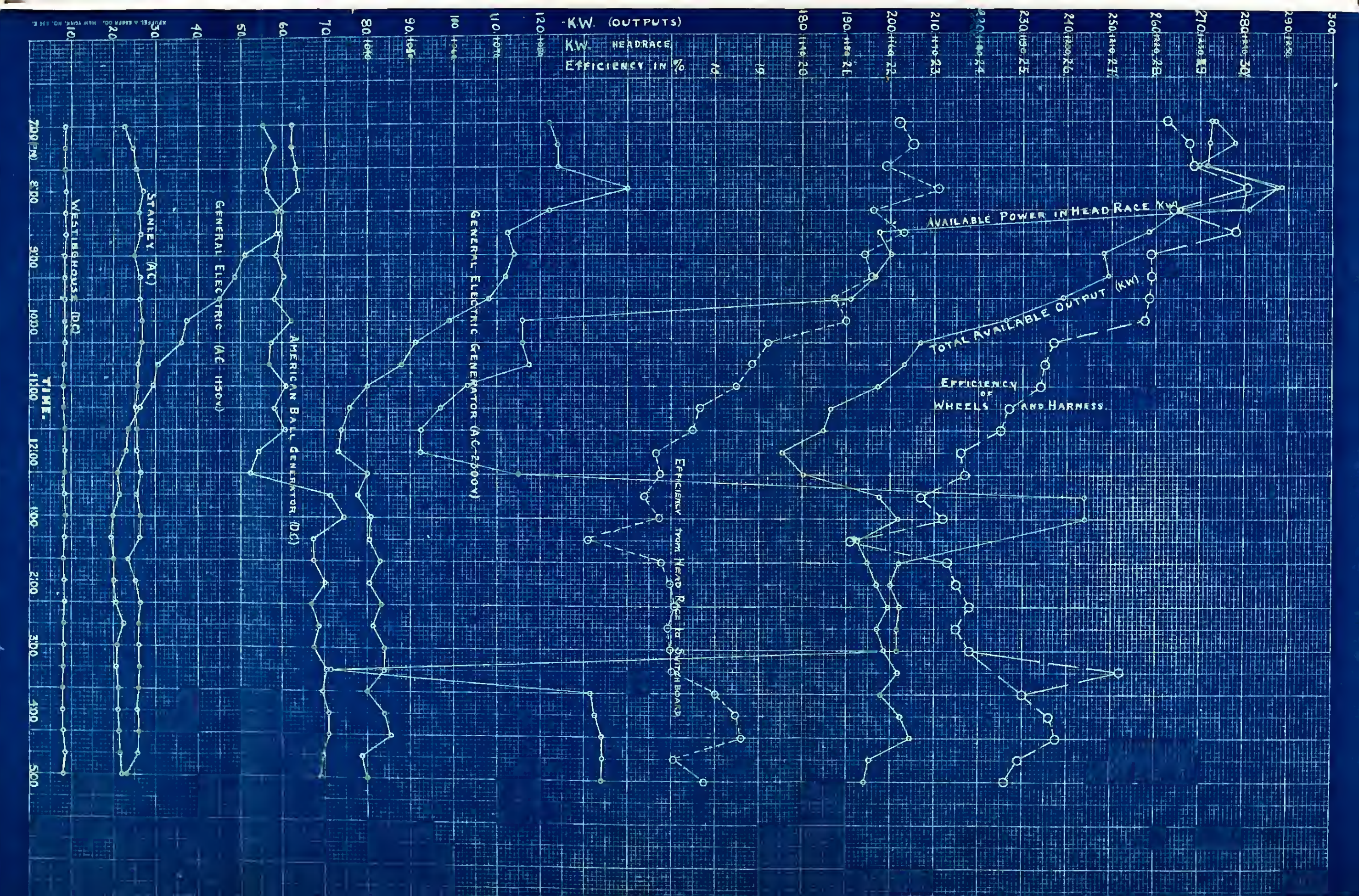
Time	We
	Ou P
7:00	8.
20	8
40	8.
8 00	8.
20	8.
40	8.
9:00	8.
20	8.
40	8.
10:00	8.1
:20	8.
40	8.
11:00	8.1
20	8.
40	8.
12:00	8.
20	8.
40	8.2
1:00	8.
20	8.1
40	8.
2:00	8.
20	8.2
40	8.1
3:00	8.2
20	8.1
40	7.9
4:00	7.
20	7.
40	8.1
5 00	7.

Note

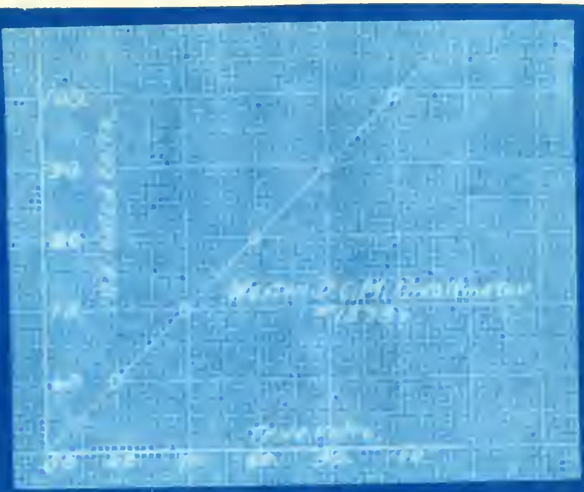
DATA SHEET

Time	Westinghouse D.C.		Ball Gen. D.C.		Stanley A.C.		G.E. A.C. 1150 V.		G.E. A.C. 2300 V.		Total available Output	Total Input	Available power in Head Race in K.W.	Eff. Head Race to Switchboard	Eff. of Wheels + Harness.
	Output K.W.	Input K.W.	Output K.W.	Input K.W.	Output K.W	Input K.W.	Output K.W	Input K.W.	Output K.W.	Input K.W.					
7:00	8.42	21.05	55.2	65.3	22.65	32.7	63.5	72.5	122	165	273.4	348.2	1232.5	22.2	28.25
20	8.49	21.2	56.2	66.5	24.75	35.4	63	72	124	167.5	277.9	354.1	1232	22.5	28.75
40	8.59	21.4	55.9	65.2	25.85	36.9	64	73	124	167.4	269.8	355.3	1231.5	21.9	28.05
8 00	8.83	22.1	56.3	66.7	27.15	38.8	65	74.5	140	185	288.5	378.3	1247.5	23.1	30.6
20	8.56	21.4	58.2	68.9	26.15	37.3	59	68	122	165	265.4	352	1241	21.6	28.4
40	8.75	21.9	59.6	70.6	26.45	37.8	59.8	69	112.4	154	258.4	344.6	1157.5	22.3	29.8
9:00	8.17	20.5	57	67.5	25.15	35.9	52.	61.5	114	146.5	248.2	323.7	1160	21.4	27.9
20	8.54	21.4	61.5	72.8	26.45	37.8	49.2	59.	112	140	249.2	322.5	1156.5	21.6	27.9
40	8.54	21.3	58.1	68.8	26.55	37.9	46.2	56.5	108	135	238.9	311.	1151	20.75	27.85
10:00	8.17	20.4	62.2	73.6	26.65	38.1	38.2	50	99	125	226.1	298.9	1076	21	27.75
:20	8.50	21.2	52.6	62.3	25.65	36.7	37.3	49.5	91.2	115.3	206.8	276.5	1076	19.2	25.7
40	8.30	20.9	67.	67.5	26.05	37.2	32.	45.5	88	112.5	203.1	275.2	1077.5	18.85	25.5
11:00	8.19	20.5	60.9	72.1	26.15	37.4	30	44.	80	104	197.1	269.8	1063.	18.5	25.4
20	8.28	20.7	58.1	68.8	25.45	36.4	27.3	42.5	76	100	186.9	260.1	1057	17.67	24.7
40	8.54	21.4	60.9	72.1	25.75	36.8	24	40.	74	96	184.7	257.8	1052.4	17.5	24.5
12:00	8.45	21.1	54.8	64.9	25.65	36.7	23.5	39.5	73.2	95	175.3	248.8	1052.4	16.65	23.6
20	8.47	21.2	52.4	62	26.45	37.8	21.4	38.	80	104	180.3	254.5	1075	16.75	23.7
40	8.28	21.2	71.4	84.5	25.55	36.5	21.6	38.3	78.8	102.5	197.4	274.7	1204	16.4	22.7
1:00	8.61	21.5	74.4	86.9	26.55	37.9	20	37.	80.9	104.5	201.9	279.2	1204	16.75	23.2
20	8.13	21.3	67.2	79.6	25.35	36.2	19.5	36	80.4	104.	192.5	269.	1273	15.1	21.1
40	8.08	20.2	68.1	80.6	23.65	33.8	20	37	83.	107	194.8	270.5	1162	16.75	23.3
2:00	8.03	20.1	70.6	83.6	25.15	35.9	20.6	37.5	80.4	104	196.8	273.1	1160	16.95	23.5
20	8.23	20.6	67	79.3	26.65	38.1	22.6	39	83.2	108	199.5	276.8	1162	17.05	23.8
40	8.18	20.5	68.7	81.3	26.15	37.4	20.9	38	81.2	104.5	197	273.5	1161.5	16.95	23.5
3:00	8.22	20.5	67.8	80.3	26.15	37.4	20.5	37.5	84.	109	198.5	276.5	1161.5	17.	23.8
20	8.18	20.5	70.2	83.1	26.15	37.4	21.4	38.2	84	109	201.8	280.	1031.5	17.	27.2
40	7.90	19.7	69.6	82.4	25.85	36.9	21.4	38.2	80	104	197.9	273.3	1091.5	18	25.
4:00	7.95	19.8	70.9	83.9	25.85	36.9	21.5	38.3	84	109	202.3	280	1092.4	18.5	25.6
20	7.98	19.9	71.	84.0	26.15	37.4	21.6	38.3	85.6	110	204.4	281.6	1094	18.68	25.75
40	8.11	20.4	69.5	82.3	25.95	37.1	21	38.	78.8	102.5	195.2	272.2	1094	17.05	24.9
5 00	7.99	2.00	69.1	81.8	22.95	32.8	22	38.5	80	104.	194.1	269.1	1094	17.75	24.6

Note – Westinghouse Polyphase Wattmeter Assumed correct. .1% error, shown by calibration.



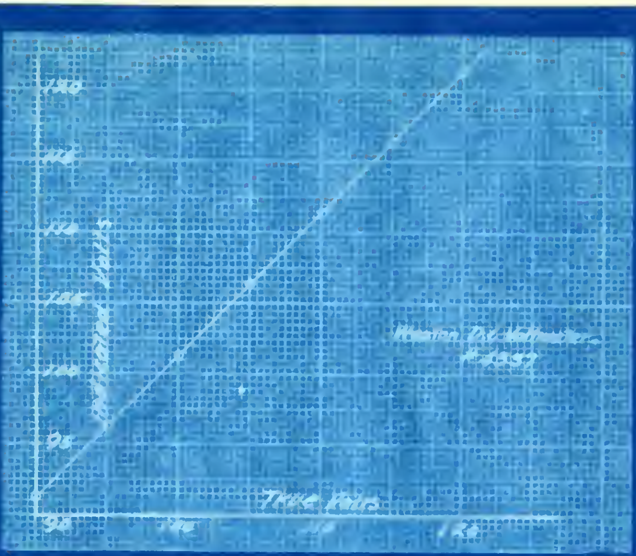
KW. (OUTPUTS)
KW. HEADRACE
EFFICIENCY IN %
10
20
30
40
50
60
70
80 1040
90 1050
100 1060
110 1070
120 1080
18
19
180 1140 20
190 1150 21
200 1160 22
210 1170 23
220 1180 24
230 1190 25
240 1200 26
250 1210 27
260 1220 28
270 1230 29
280 1240 30
290 1250
300
TIME.
7:00 P.M.
8:00
9:00
10:00
11:00
12:00
1:00
2:00
3:00
4:00
5:00
WESTINGHOUSE (D.C.)
STANLEY (AC)
GENERAL ELECTRIC (AC 1150v)
AMERICAN BALL GENERATOR (D.C.)
GENERAL ELECTRIC GENERATOR (A.C. 2300v)
EFFICIENCY from HEAD RACE to SWITCHBOARD
TOTAL AVAILABLE OUTPUT (KW)
AVAILABLE POWER IN HEAD RACE KW
EFFICIENCY OF WHEELS AND HARNESS



#15386 Weston (0-10) D.C. Millivoltmeter

True	50	60	70	80	90	100
Indicated	50	60	70	80	90	101

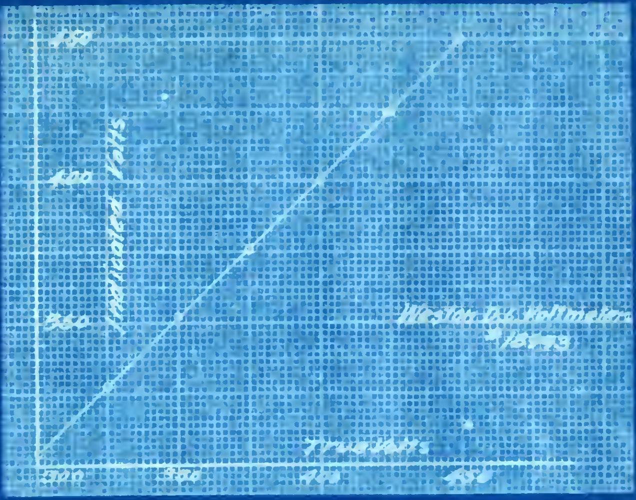
INSTRUMENT CALIBRATION



Weston (0-150) D.C. Voltmeter # 4337

True	90	95	100	105	110	115	120
Indicated	91.25	96.25	101.25	106.3	111.4	116.35	121.4

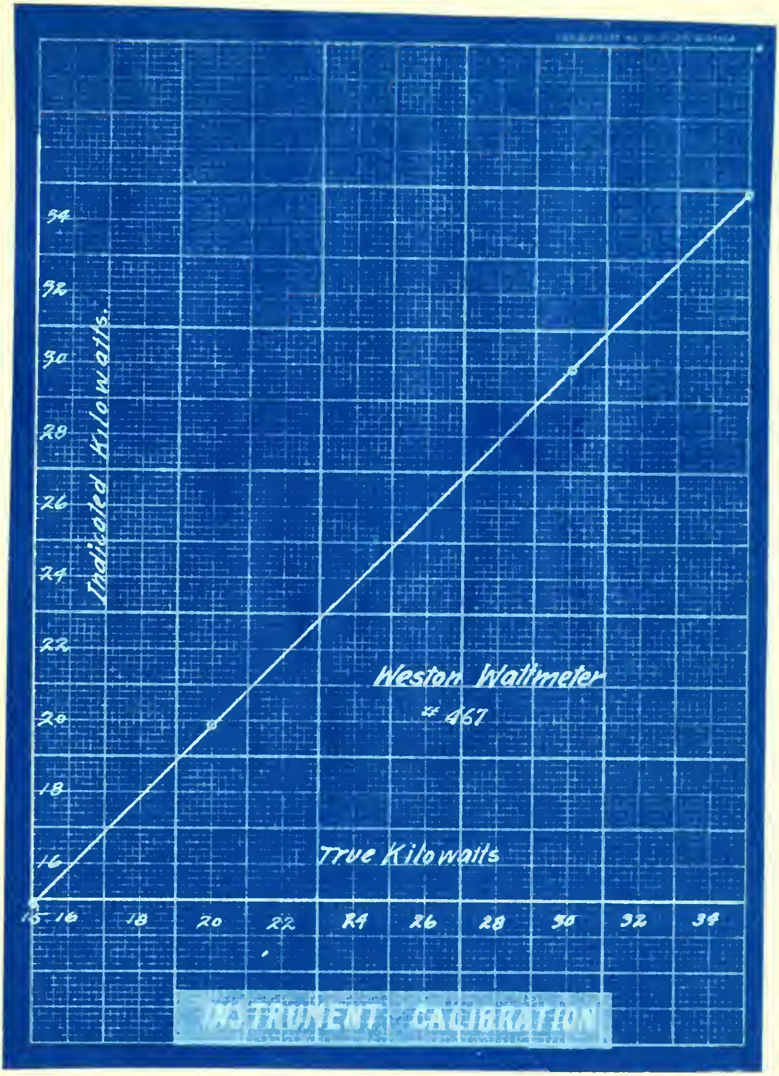
INSTRUMENT CALIBRATION.

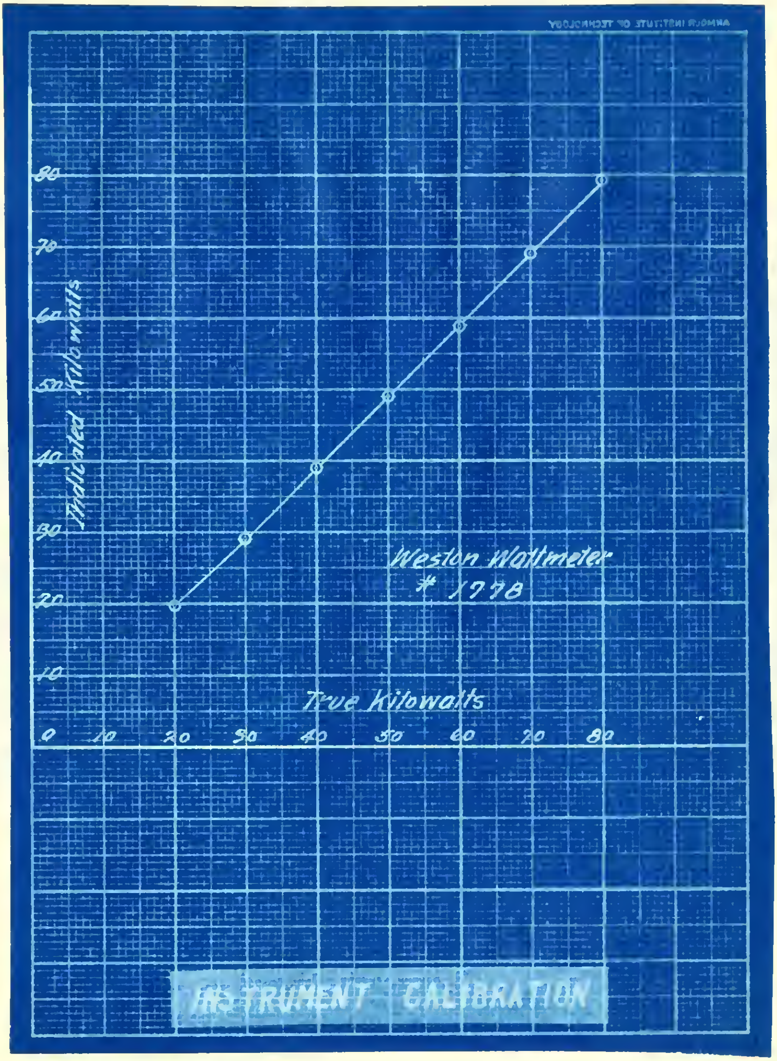


#18993 Weston (0-750) Voltmeter.

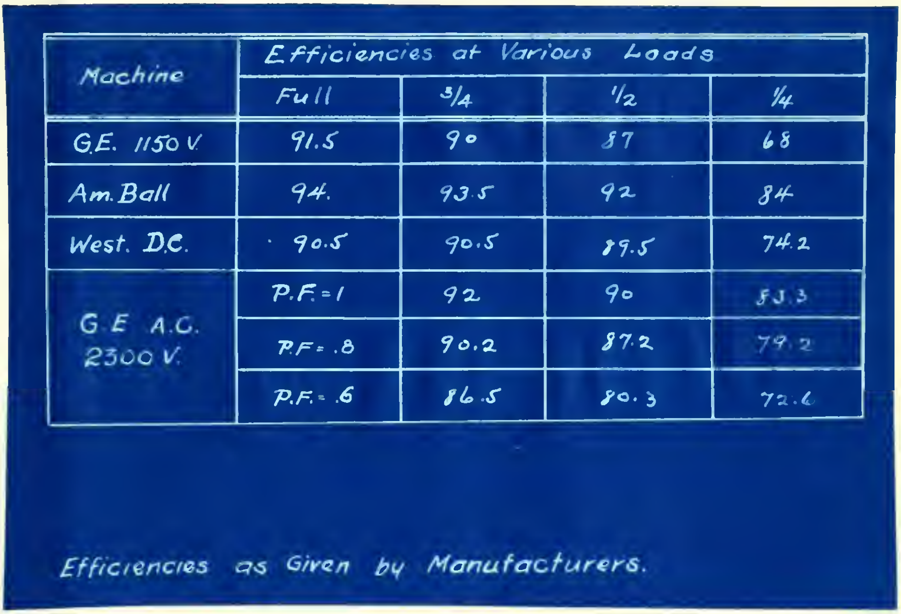
True	300	325	350	375	400	425	450
Indicated	305	327.5	352.5	376.3	400	425	450

INSTRUMENT CALIBRATION.


Indicated Kilowatts.
34
32
30
28
26
24
22
20
18
16
Weston Wattmeter
# 467
True Kilowatts
15
16
18
20
22
24
26
28
30
32
34
INSTRUMENT CALIBRATION



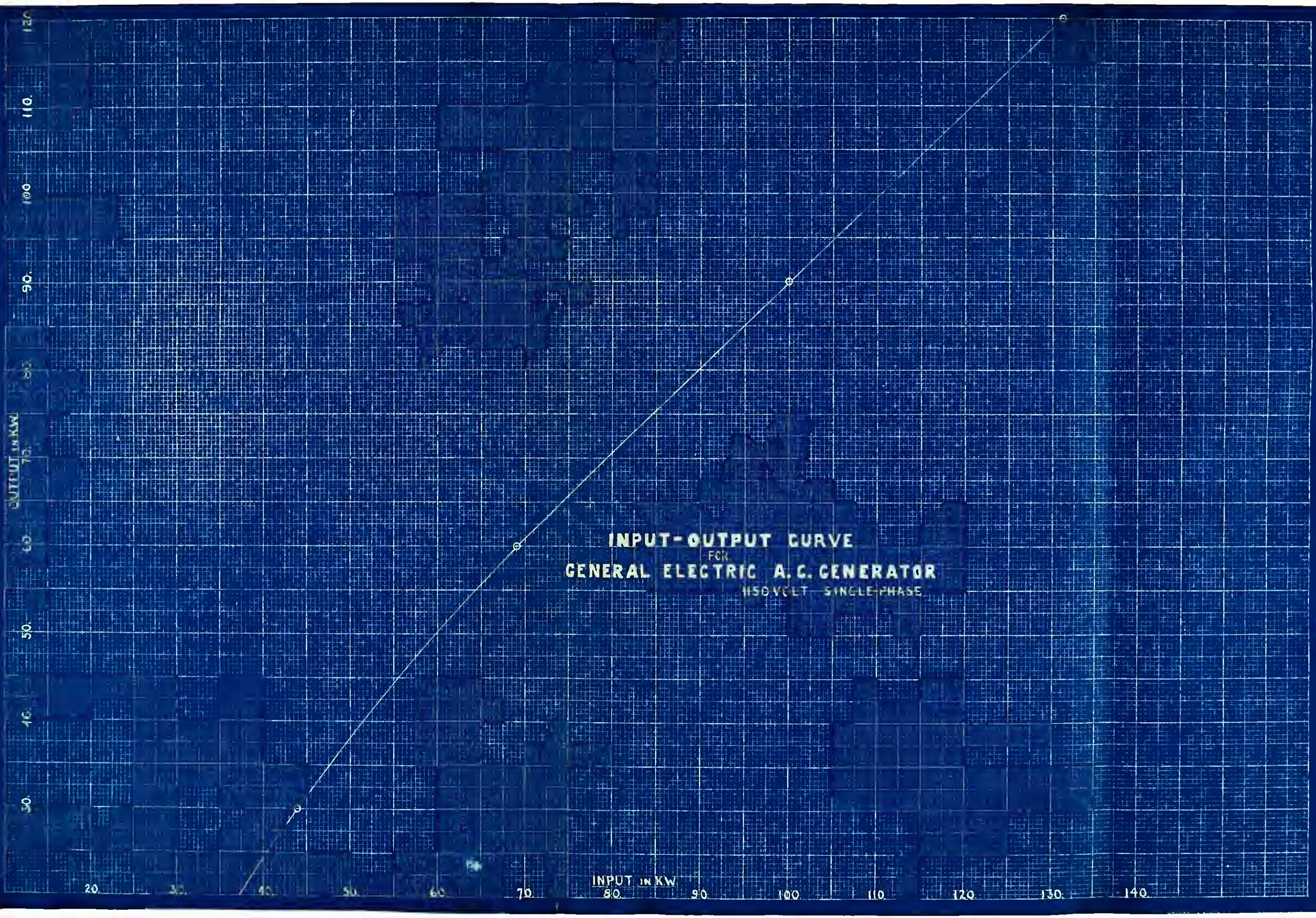
INSTRUMENT CALIBRATION



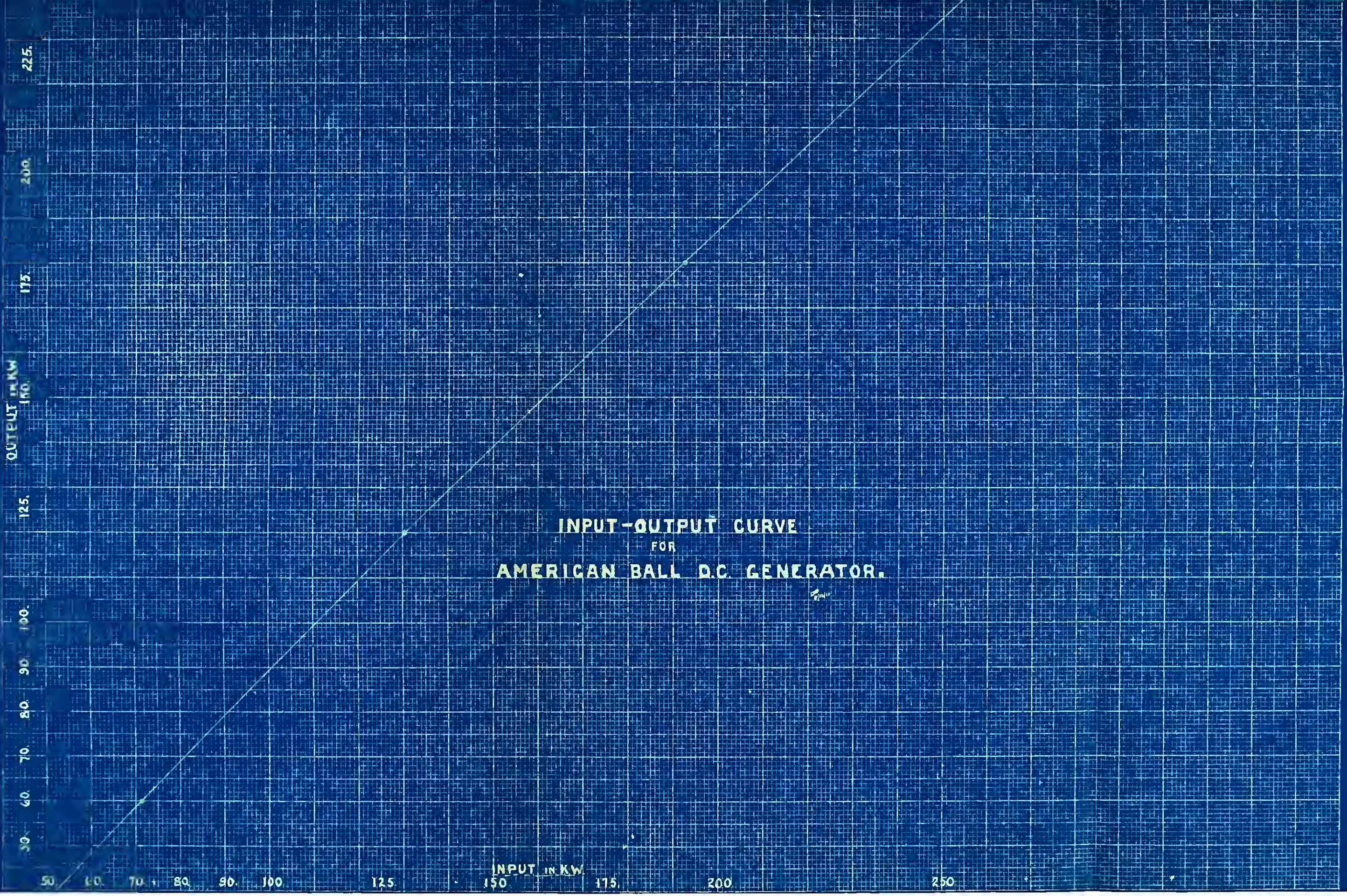
Machine	Efficiencies at Various Loads			
	Full	3/4	1/2	1/4
G.E. 1150 V.	91.5	90	87	68
Am. Ball	94.	93.5	92	84
West. D.C.	90.5	90.5	89.5	74.2
G.E. A.C. 2300 V.	P.F.=1	92	90	83.3
	P.F.=.8	90.2	87.2	79.2
	P.F.=.6	86.5	80.3	72.6

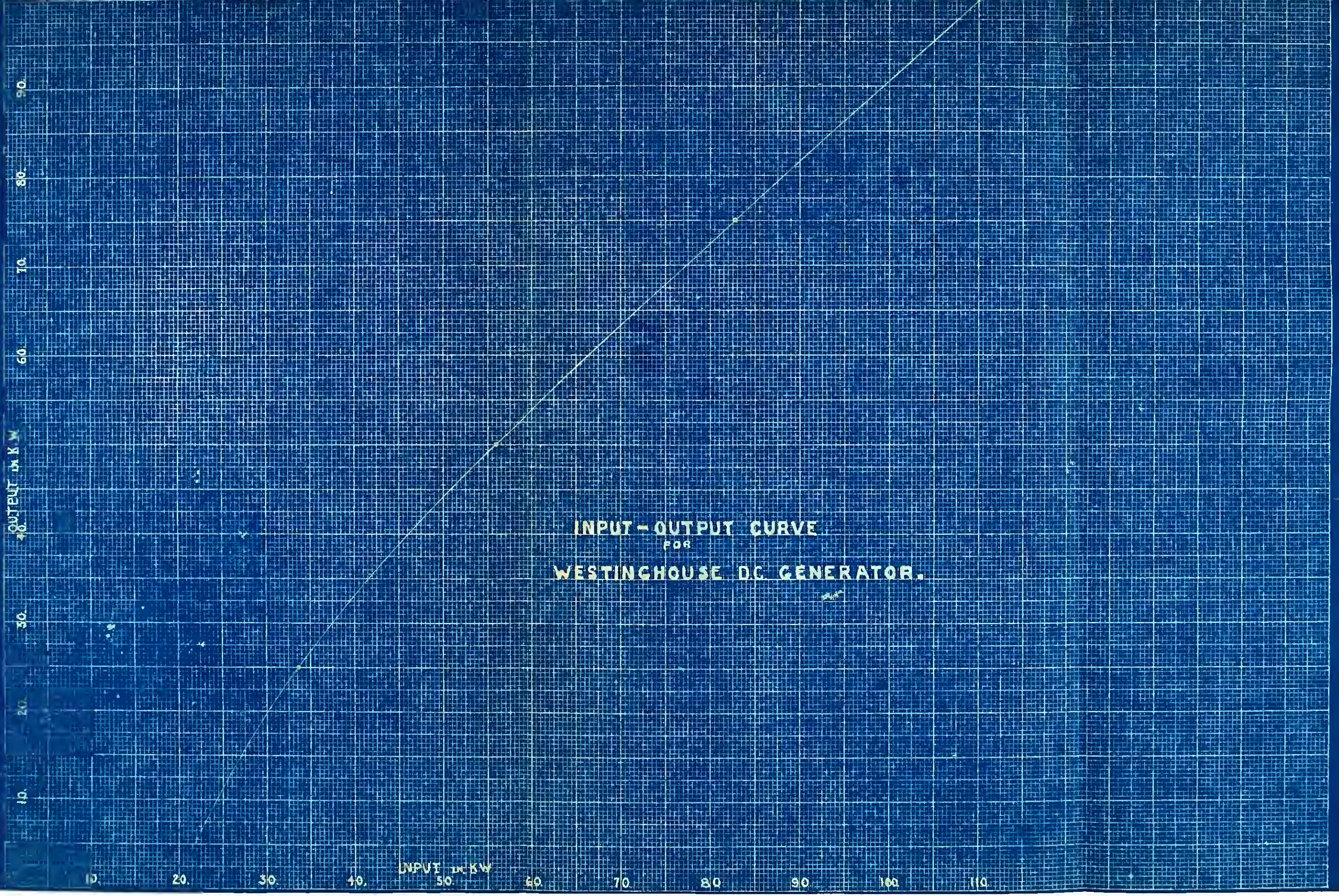
Efficiencies as Given by Manufacturers.

OUTPUT KW

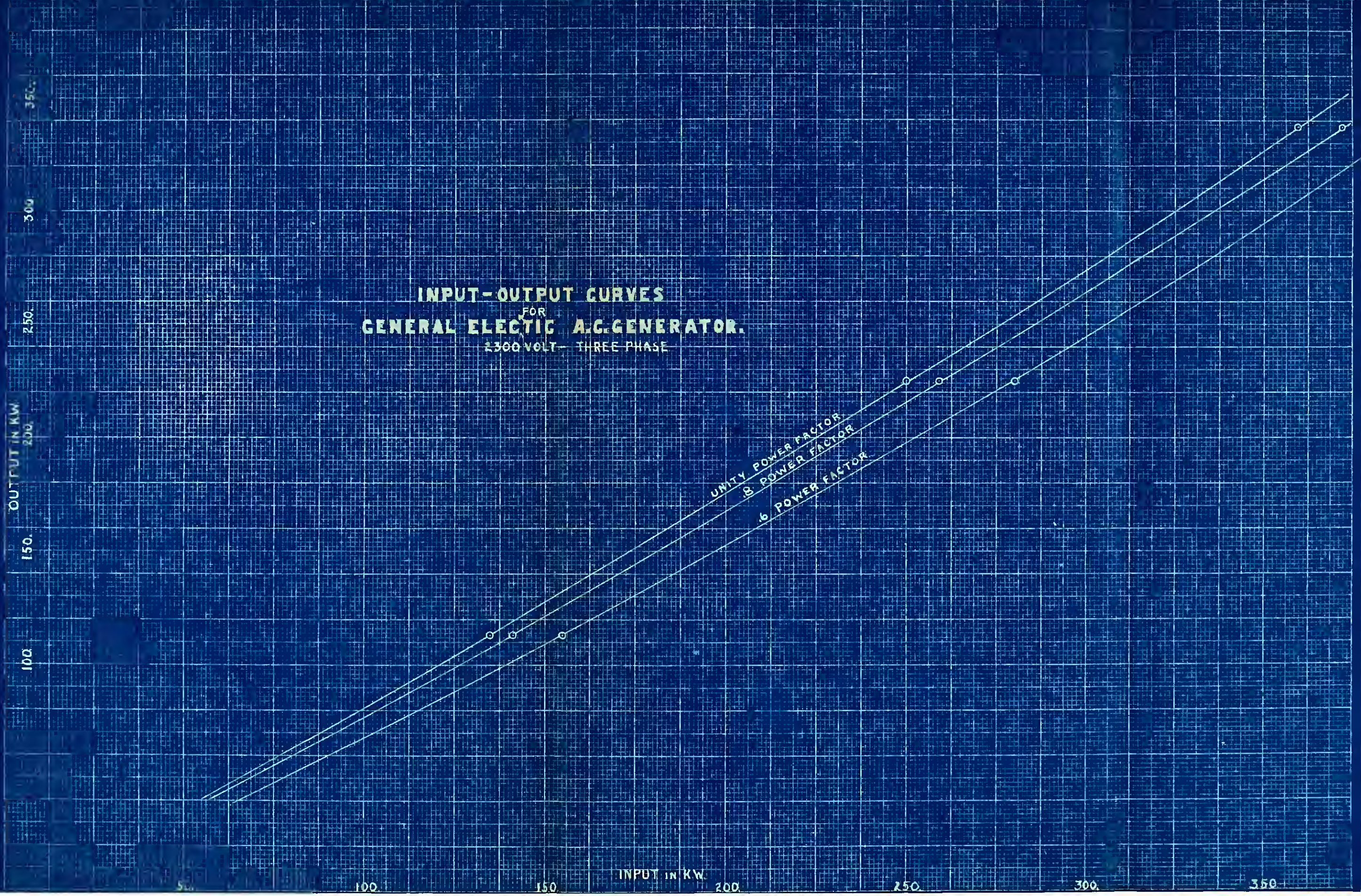


INPUT-OUTPUT CURVE
FOR
GENERAL ELECTRIC A.C. GENERATOR
1150 VOLT SINGLE-PHASE


INPUT-OUTPUT CURVE
FOR
AMERICAN BALL D.C. GENERATOR.



INPUT - OUTPUT CURVE
FOR
WESTINGHOUSE DC GENERATOR.



INPUT-OUTPUT CURVES
FOR
GENERAL ELECTIC A.C. GENERATOR.
2300 VOLT - THREE PHASE

Conclusions.

The results obtained show the plant to have a very poor efficiency. This is true of both the wheel end and the generating end. A consideration of the low lead under which the plant is operating will ezplain the poor showing. The efficiency of the generating end drops off not to exceed 20% from full load to 1/4 load, about the condition under which the plant is operating. The efficiency of the wheels of all such primemovers in fact, drops off very rapidly for a decrease in load.

It was of course impossible to make any determination as to the efficiencies at transmissions from crown wheels (the level gear on the wheel shaft) to generators; it would be entirely reasonably to assume the efficiency of transmission to be 75% as all bearing were well lubricated and the gearing was in good condition. This would give the actual wheel efficiency as about 35%, a somewhat low figure when compared to brake efficiency tests cited by numerous experimenters.

The assumption of 75% as the efficiency of transmission is not high as Prof. C. M. Allen in an article, in Vol. 32 (April 1910) of the Trans. A.S.M.E., that bevel gearing under similar conditions used in installations which he has tested has shown efficiencies varying from 85 to 97%.

It was of course, impossible to measure the wheel leakage and there may have been a large amount of it. Leakage around the draft tubes and through the wheel pit floor was not great; as the wheel pit was inspected during a period of shut down for repairs previous to the test. The wheels have been installed for a number of years, and although kept in repair, may not have been in the best possible condition, very evidently so from results obtained.

In the calculations, no account of any loss in transmission by belts was considered, the efficiency e_2 being taken from the available power in head race to the generators. This loss should have been added to the input if the efficiency to the line shaft input had had been desired. After calculations, involving the rotative speeds of the generators and the pulley had been made, the loss was found to be entirely negligible,

it was therefore not considered. It may be stated in this connection that the belts were very taut, liberal in size and in very good condition.

The error in assuming figures given by manufacturers for efficiencies should not be over 5% as the machines have been kept in good shape. It should be thoroughly understood,however, that the determination of e_2 which involves these figures is open to criticism as various factors effect them. As it was the only means to an end it was necessarily adopted. The efficiency e_1 from head race to switch board, may be taken as accurate to 1% as all instruments read closer than 1% and have been checked in all instances.